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Surface run-off in railroad track ballast section filtration analysis and characteristics

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Abstract

Railway facilities are usually defined as stationary engineering structures that constantly influence environment. Railway stations are main contaminators in railroad sector. Usually contaminated surface run-off coming from railroad tracks of railway stations is the result of atmospheric precipitation. Surface run-off flows through surface relief deep into the soils. Then it joins ground flows and enter the nearest surface waterbodies. The paper gives analysis of surface run-off filtration through multi-layer porous medium in ballast section of railroad tracks. The authors describe liquid behaviour and properties in multi-layer porous medium. The particular attention is paid to liquid which concentrates on the surface of railroad tracks ballast section as a result of atmospheric precipitation. The paper also considers stationary and non-stationary liquid weepage into railroad tracks ballast section and spilled petroleum products spreading.
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*Keywords:*filtration; surface run-off; petroleum products; ballast section; railroad track.

1. Introduction

As far as great attention is paid today at nature protection requirements, environmental pollution problems they solution and control measures are undoubtedly actual and important. Surface waste water coming from railroad right-of-way is considered to be one of the major environmental pollutants. There is no standard system of surface

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waste water (coming from railroad constructions) disposal. For that reason there is no existing regulation concerning contaminating materials and their possible amount in surface waste water. The authors are sure that surface waste water collecting, disposal and purification should become the focus of environmentalists immediate attention.

Railway stations are main contaminators in railroad sector [6, 9]. Usually contaminated surface run-off coming from railroad tracks of railway stations is the result of atmospheric precipitation. Surface run-off flows through surface relief deep into the soils. Then it joins ground flows and enter the nearest surface waterbodies.

2. Basics

2.1. Structure

Primary equations for liquid filtration in porous medium are considered [1, 2] to be the equation of continuity $\partial(\rho m)/\partial t + div(\rho\vec{u}) = 0$ and Darcy's law $-grad(p) + \rho\vec{g} - \mu\vec{u}/k = 0$ in which ρ is liquid density; m is medium porosity (that is relative proportion of open cells in a certain material); $\vec{u}$ is liquid filtration speed ($\vec{u} = m\vec{v}$ where $\vec{v}$ is liquid motion average speed in porous medium);t is time; p is liquid pressure; $\vec{g}$ is free-fall acceleration; μ is absolute viscosity of liquid; k is porous medium penetration (or penetration coefficient).

The optimal solution for this set of equations is $p = 0$, $\vec{u} = C(\vec{g}/g)$, where $C = k\rho g/\mu$ is liquid filtration coefficient in a certain medium. It is clear that this solution shows liquid free-flow in porous medium under the action of gravity. This solution makes clear the two physical meanings of the filtration coefficient. Firstly, C is speed of this liquid free-flow gravitational filtration in a certain porous medium. Secondly, C is the liquid maximum volume in a definite unit of time (discharge) on a definite area unit which is capable of free-flow filtrationin this medium. Porosity and water filtration coefficient of different medium typical value (measured by the researchers) are given in Table 1.

Table 1. Porosity and filtration coefficient of different medium typical value.

Material	*m*, %	*C*, m/s	Material	*m*, %	*C*, m/s
Brokengranit 40x70 mm	46.0	0.01	River sand 1 mm	15.0	$0.51x10^{-3}$
Brokengranit 20x40 mm	45.2	0.004	Fluvialsoil	60.0	$0.40x10^{-5}$
Brokengranit 5x20 mm	44.8	$0.18x10^{-2}$	Sandclay	75.0	$0.22x10^{-5}$
Quartzsand 2-3 mm	30.0	$0.10x10^{-2}$	Clay	50.0	$0.23x10^{-7}$

Let us suppose that there is a certain liquid accumulation (a puddle) on the surface of homogeneous porous medium (soil). In this case a so-called "nonpressure pipe" appears under this puddle and within its borders. Liquid in this nonpressure pipe goes down at *C/m* speed:

A permanent solution here is possible only if the level of the liquid on the surface goes on to recommence. In other cases the liquid is completely absorbed and in porous medium there is constant weeping. Its front (lower) edge replicates the bottom profile of the liquid which has concentrated on the surface and its back (upper) edge replicates the same bottom profile with coefficient of stretch k_{st} = 1/m -1 (as Fig. 1 shows):

Thus, we can estimate possible time of the puddle absorption using the following correlation: $T_s = h_{max}/C$ where h_{max} is the puddle maximum depth at the starting point.

This supposition is violated when getting closer to the different environment (the different filtration coefficients) border;

- Water location back (upper) edge ($C_{upper\ edge}$);
- Water location front (lower) edge ($C_{lower\ edge}$);

The hypothesis that both the form and spacing of the cross section of the water flow pipe is equal in both media if the filtration speed is simultaneously changed (form $C_{upper\ edge}$ to $C_{lower\ edge}$) contradicts the equation of continuity. It means that some additional pressure appear near the media border. This pressure leads to $_{upper\ edge} > C_{lower\ edge}$ water flow widening.

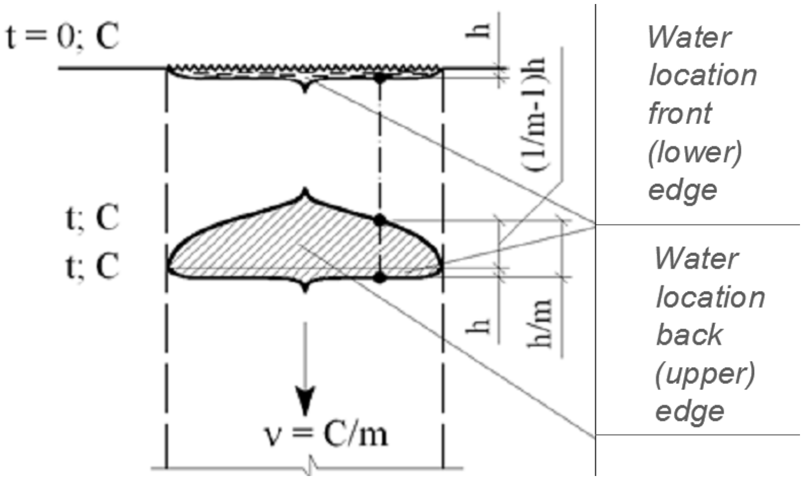

Fig. 1.Water filtration diagram with account of coefficient of stretch k_{st}; h - being surface liquid depth, m.

Here we introduce the concept of filtration flow intensity for a certain medium as a maximum liquid volume in a definite unit of time on a definite unit of surface 1_{max} which is capable of free-surface filtration throuth this medium. This definition means that q_{max}=C; which leads to another physical meaning of filtration coefficient.

Now we analyze some particular aspects of surface run-off from railroad tracks filtration.

2.2. Surface run-off filtration from railroad tracks

Let us assume that this area precipitation rate is q_{20} [1]. Liquid accumulation absence on porous medium surface and in liquid filtration pipes (when all soil interstices are filled) can be shown as follows: $q_{max}>q_{20}$. Let us compare q_{20} = 70 l/(s·ha) = $0{,}7\cdot10^{-5}$ m/s (typical for Samara region) with the data presented above in Table 1. We realize that no matter what real precipitation rate is there is no liquid accumulation on either sand or gravel surface. It leads us to the assumption that rain water flows immediately through ballast section gravel and sand layers and comes down to the main soils. The most likely scenario then can unfold in either of the following ways: if the main soils are water-permeable, rain water drains down to the nearest waterproof layer;if the main soils are not water-permeable enough (either clay or fluvial soil or sand clay), rain water starts accumulating on the boarder between sub-ballast and the main soils. This underground liquid accumulations slowly leak water down into the soils.

If we put water-permeable geofabric on the boarder between sub-ballast and the main soils it will change nothing. But if we put waterproof geofabric on the border between sub-ballast and the main soils it would prevent water from leaking further down. Thus, we make a kind of water-bearing layer. It makes liquid flow horizontally up to the geofabric edge. Then this liquid flows out of ballast section in lateral direction generating road-side puddles which later sink into soils.

2.3. Stationary weepage filtration

Let us consider a situation when there is some stationary liquid weepage (that is usually very polluted water) in a certain area. It punctually drenches ballast section surface, its volume flow rate being QQQ ($m^3/(m^2s)$=m/s). In this case there is a filtration channel developing gradually under the leekage point, its radius being $R = \left(Q/\pi C\right)^{1/2}$. The filtration channel radius depends on porous medium character. The channel in gravel is narrower than it is in sand, and the channel in sand is narrower than it is in soils: $R_{gr} < R_{sand} < R_{soils}$.

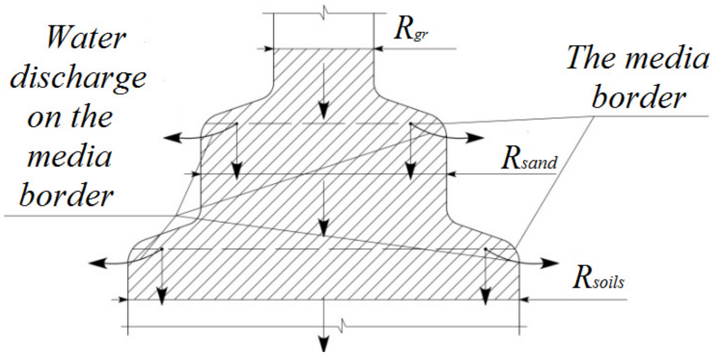

Fig. 2. Liquid filtration channel widening and water discharge on the medium border.

For this reason a filtration channel widens both on the boarder of gravel and sand and on the boarder of sub-ballast and soils (as seen on Fig. 2). When some part of the filtration channel goes beyond railway embankment it leads to liquid discharge in lateral direction (either on the boarder of gravel and sand or on the boarder of sand and soils).

Let us consider $R_{\max}$ to be a filtration channel the maximum permissible radius (that is a distance between the center of one 11.7 m railroad track, the railroad here being double track to the edge of the railway embankment, $R_{\max}$ =11.7/4 = 2.925 m [2, 4]). In this case the maximum permissible liquid leakage up to the point of its discharge in the lateral direction is $Q_{\max} = \pi C R_{\max}^2$.

The researcher calculated the maximum permissible liquid leakage basing upon the filtration coefficient typical values. While calculating we assume the main soils to be sand clay, sand foundation to be of river sand, its upper layer to be broken granite of 40×70 mm.

Table 2. Variants of liquid behaviour while weeping.

№	Situation	Result
1	$Q < Q_{soils}$ =0.59 l/sec	Water flows through gravel within the railroad embankment.
2	0.059 l/sec = $Q_{gr} < Q < Q_{sand}$ = 14.0 l/sec	Water flows through gravel and sand within the railroad embankment, a lateral discharge of water originating on the border of sub-ballast and gravel (some water flowing farther into the soils outside the railroad embankment).
3	14.0 l/sec = $Q_{sand} < Q < Q_{gr}$ = 269.0 l/sec	Water flows through gravel within the railroad embankment. There is a lateral discharge of water originating on the boarder of gravel and sand. Some water goes on flowing farther through the sand. There is the second lateral discharge of water originating on the boarder of sand and soils.
4	$Q > Q_{gr}$ =269.0 l/sec	Some water goes on flowing farther through gravel; some water goes through gravel within railroad tracks. There is a lateral discharge of water originating on the boarder of gravel and sand. Some water goes on flowing farther through the sand. There is the second lateral discharge of water originating on the boarder of sand and soils.

Thus, we come to the conclusion that regular liquid filtration into soils (itsweepage) is not typical here. It is more common that liquid is discharged into the slope drain on the border of ballast section and soils.

2.4. Petroleum products filtration

Now we consider petroleum products filtration (e.g. crude oil) when split on railroad tracks [5, 7].

All equations presented in the previous part of our research work here as well. There are, though, some quantitative changes which are due to greater viscosity of petroleum products .

In fact, water viscosity (at 20° C) μ_{water} = 1.002*10^{-3} Pa*s, its density ρ_{water}=10^3 kg/m^3. Crude oil viscosity μ_{oil} = (100…200)*10^{-3} and more Pa*s, its density ρ_{oil}being (0.8 ...1.0)*10^3 kg/m^3. There is very littler difference in there density while their viscosity is 100 ... 200 times as different. One should also take into account that oil viscosity dramatically rises at low temperatures and that some petroleum products viscosity (e.g. industrial fuel oil) is even greater than that of crude oil.

Penetration coefficient of the medium does not depend on the properties of liquid [3, 4]. That is why penetration coefficients co-relation for one and the same liquid in different media does not depend on the properties of liquid either. It means that the geometric formula (given above) are the same both for water and petroleum products. It is important, though, that time required for petroleum products filtration is μ_{oil}/μ_{water} approximately 100 ... 200 ... times longer. In other words, petroleum products filtration goes on the same way as water filtration but it takes 100 ... 200 times longer.

In particular, we can suppose that $\mu_{oil}/\mu_{water} \approx 100$ we have$t_{gravel/sand} \approx 2300$ sec ≈ 38 min, $\Delta t_{gravel/sand} \approx 500$ sec ≈ 8 min, $t_{sand/soils} \approx 14700$ sec ≈ 4 hours, $\Delta t_{sand/soils} \approx 9800$ sec ≈ 3 hours.

It means that ballast section and its sub-ballast are drained from crude oil within several hours in summer but they are drained within several days and even weeks from viscous petroleum products or in winter. It may lead to the following results: a certain "waterdrop" flowing through a certain medium might gain an "oildrop" (which goes more slowly). Then there might be a lateral discharge of water enriched with petroleum products. In this case it may happen not on the medium border (as usual) but in any place where these two drops mix. Consequences are almost the same if petroleum products of different viscosity mix while flowing. In both cases pollutants are not only absorbed by soils but are also discharged in the lateral direction (see Fig. 3).

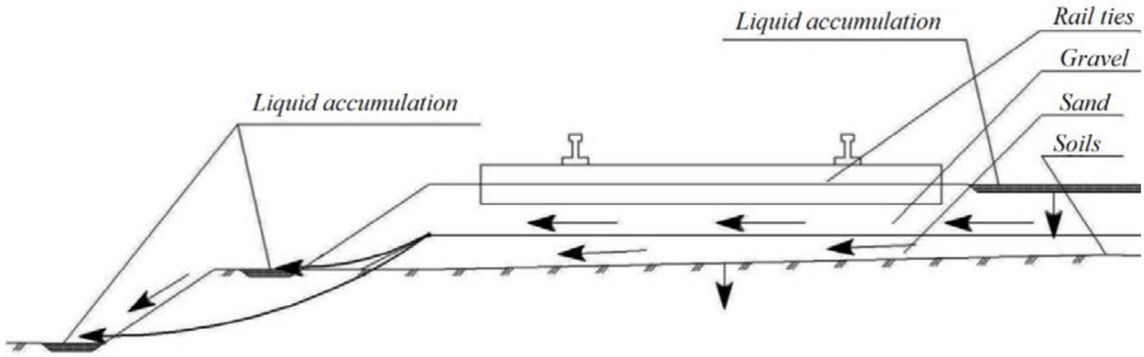

Fig. 3. Fluid weepage, outlet and discharge on different environment boarder.

3. Conclusions

The research proves that any liquid which lands on railroad tracks goes on flowing down the railway embankment and then turns in the lateral direction. It happens either on the boarder of ballast section and sub-ballast or on the boarder of sub-ballast and soils.

Thus, we can conclude that if ballast section pollutants (discharged in the lateral direction) are properly collected and then utilized or disposed, environmental damage arising of railroads use can be reduced to a minimum. It is also very important that in this case ballast section reliable performance grows upward as well [8, 9].

For proper and regular work of the upper part of railroad tracks (its ballast section in particular) the following conditions can be introduced:

- the upper part of railroad tracks should be equipped with trench drains for taking surface run-off away from ballast section;

- surface run-off from railroad tracks should flow into a certain storage basin. Surface run-off should also be controlled while further led into water and wastewater treatment facilities (both stationary and mobile) [10].

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